LMS/RUL/S04617

Rulison Path Forward

June 2009

U.S. DEPARTMENT OF ENERGY | Office of Legacy Management

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Executive Summary

The U.S. Department of Energy (DOE) Office of Legacy Management developed this report as a guide for discussions with the Colorado State regulators and other interested stakeholders in response to increased drilling for natural gas reserves near the underground nuclear explosion site at Rulison, Colorado.

The Rulison site is located in the Piceance Basin of western Colorado, 40 miles northeast of Grand Junction. The Rulison test was the second natural gas reservoir stimulation experiment in the Plowshare Program, which was designed to develop peaceful uses for nuclear energy. On September 10, 1969, the U.S. Atomic Energy Commission, a predecessor agency of DOE, detonated a 40-kiloton nuclear device 8,426 feet below the ground surface in an attempt to release commercially marketable quantities of natural gas. The blast vaporized surrounding rock and formed a cavity about 150 feet in diameter. Although the contaminated materials from drilling operations were subsequently removed from the surface of the blast site, no feasible technology exists to remove subsurface radioactive contamination in or around the test cavity.

An increase in drilling for natural gas near the site has raised concern about the possibility of encountering residual radioactivity from the area of the detonation. DOE prohibits drilling in the 40-acre lot surrounding the blast site at a depth below 6,000 feet. DOE has no evidence that indicates contamination from the Rulison site detonation has migrated or will ever migrate beyond the 40-acre institutional control boundary. The Colorado Oil and Gas Conservation Commission (COGCC) established two wider boundaries around the site. When a company applies for a permit to drill within a three-mile radius of surface ground zero, COGCC notifies DOE and provides an opportunity to comment on the application. COGCC also established a half-mile radius around surface ground zero. An application to drill within one-half mile requires a full hearing before the commission.

The report outlines DOE's recommendation that gas developers adopt a conservative, staged drilling approach allowing gas reserves near the Rulison site to be recovered in a manner that minimizes the likelihood of encountering contamination. This staged approach calls for collecting data from wells outside of the half-mile zone before drilling closer, and then drilling within the half-mile zone in a sequential manner, first at low contamination probability locations and then moving inward. This approach is DOE's recommendation for drilling in this area that will protect public safety while allowing collection of additional data to confirm that contamination is contained within the 40-acre institutional control boundary.

1.0 Introduction

In response to increased drilling for natural gas reserves near the Project Rulison underground nuclear test site (Rulison site), the U.S. Department of Energy (DOE) is developing a path forward as a guide for discussions with the Colorado Oil and Gas Conservation Commission (COGCC) and natural gas operators with nearby lease interests.

1.1 Location and Background

The Rulison site is located in the Piceance Basin of western Colorado, 40 miles northeast of Grand Junction in Garfield County, Section 25, T7S, R95W, 6th Principal Meridian (Figure 1). The Mesaverde Group formations within the Piceance Basin (Figure 2) contain significant reserves of natural gas in poorly connected, low-permeability (tight) sandstone lenses. The Rulison test was designed and conducted to evaluate the use of a nuclear detonation to enhance gas production in these tight sandstone reservoirs.

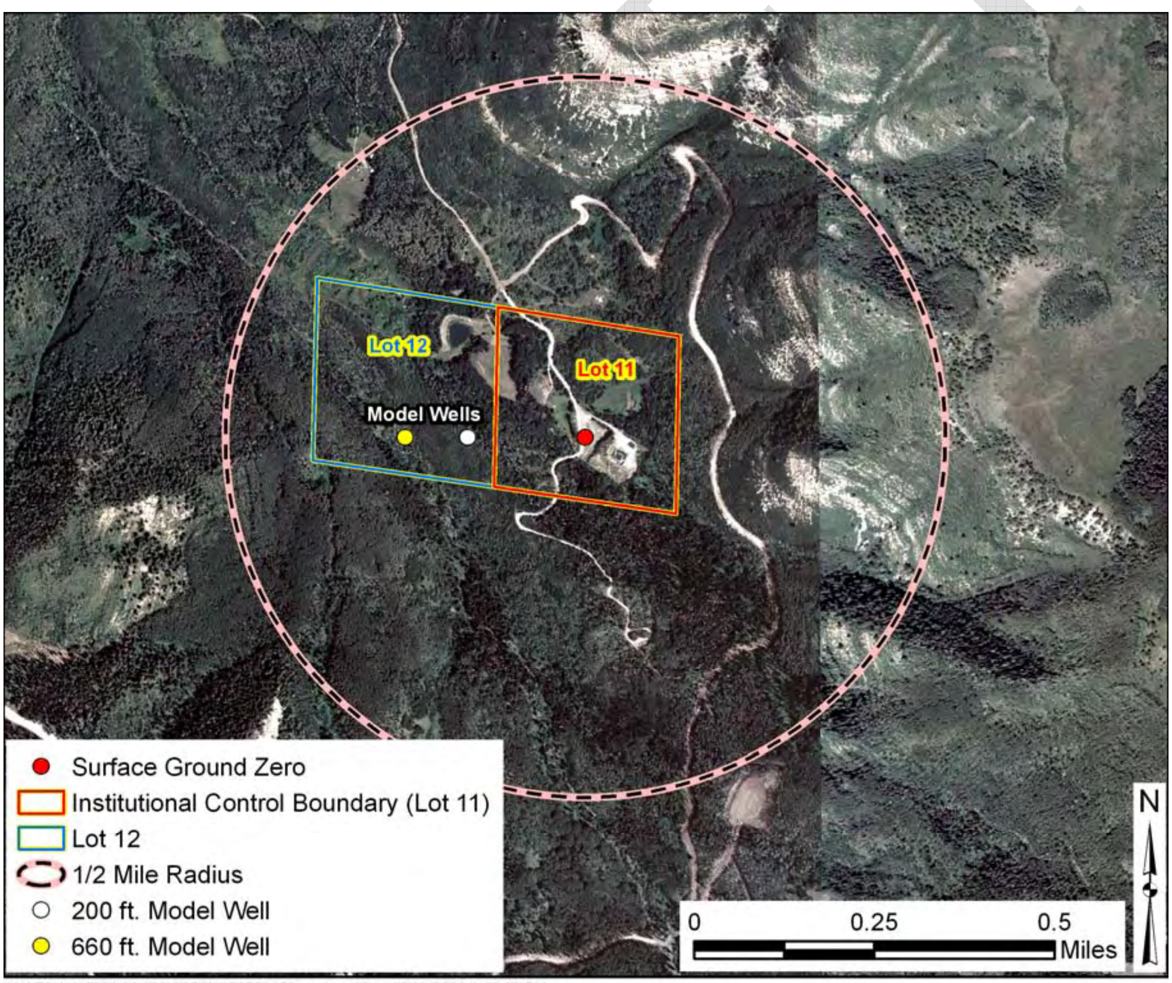


Figure 1. Current Institutional Control Boundary (Lot 11) and the Half-Mile Hearing Radius

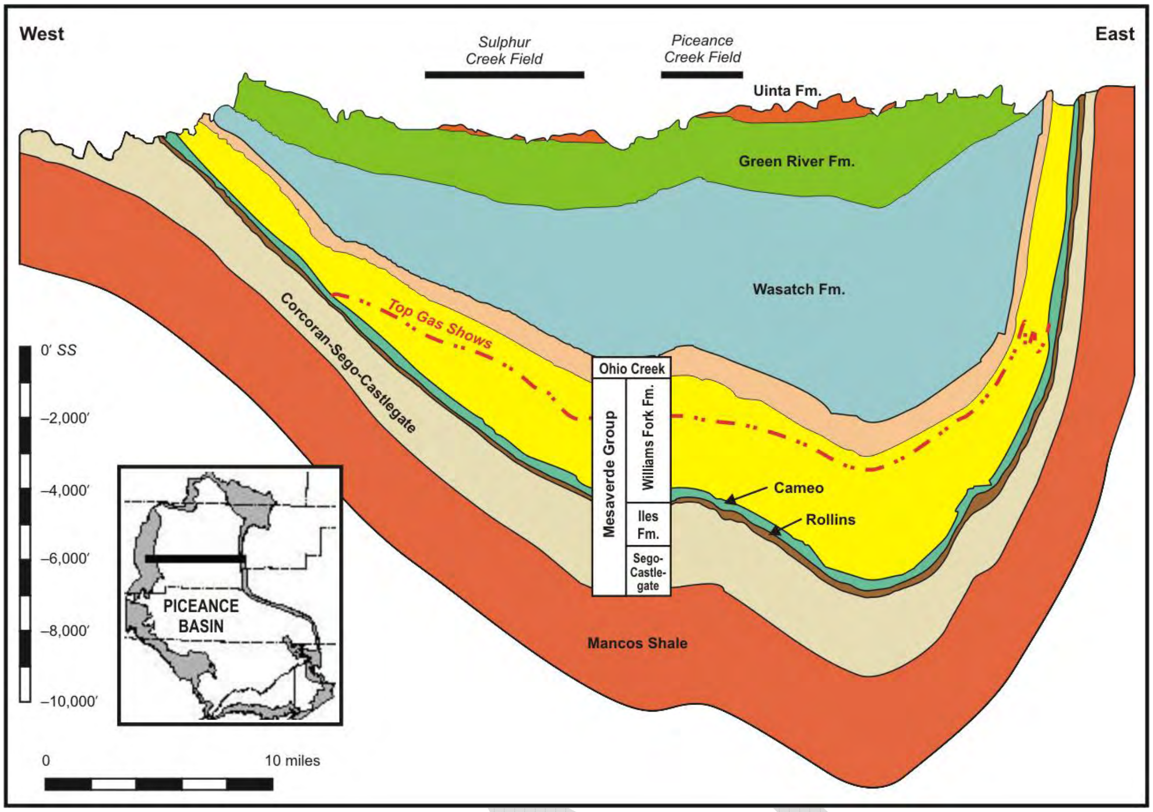


Figure 2. Piceance Basin Cross Section (modified from Yurewicz 2003)

A 43-kiloton device was detonated on September 10, 1969, at a depth of 8,426 feet (ft) below ground surface in the Williams Fork Formation of the Mesaverde Group. The detonation created a cavity, a chimney, and a fractured zone surrounding the cavity (detonation zone). A highly fractured area encountered by the reentry well 275 ft above the detonation level was interpreted as the top of the chimney (Figure 3). Four production tests conducted on the reentry well between October 1970 and August 1971 produced a total of 455 million standard cubic feet of natural gas. It was estimated that the volume of gas generated during the testing was approximately 10 times that of a conventionally stimulated well in the same production zone (AEC 1973). The concentrations of radionuclides dropped throughout the production testing, but the remaining presence of radionuclides within the produced gas made it unmarketable. The reentry well was shut in after the final test in 1971 and remained so until abandonment in 1976 (IT 1996). Drilling at the site was limited to the exploratory well (Hayward A 25-95 [R-EX]), the emplacement well (Hayward A 25-95 [R-E]), the reentry well (a sidetrack from the exploratory well after the detonation), and one shallow instrument hole (CER test well). Near-surface nonradiological contamination associated with the drilling mud pits and effluent pond was remediated in 1996, and the Rulison Site Surface Closure Report was published in July 1998.

The ability to enhance natural gas production from tight sands has recently become feasible through advances in hydrofracturing technology. Fluids with entrained sand are pumped into the gas reservoirs at high pressure, creating fractures that extend outward from the wellbore. After fracturing, the fluid is pumped out, and the sand remains to keep the fractures propped open, enhancing gas flow to the well. With the combination of technological advances in hydrofracturing, higher natural gas prices, and increased demand, gas development near the

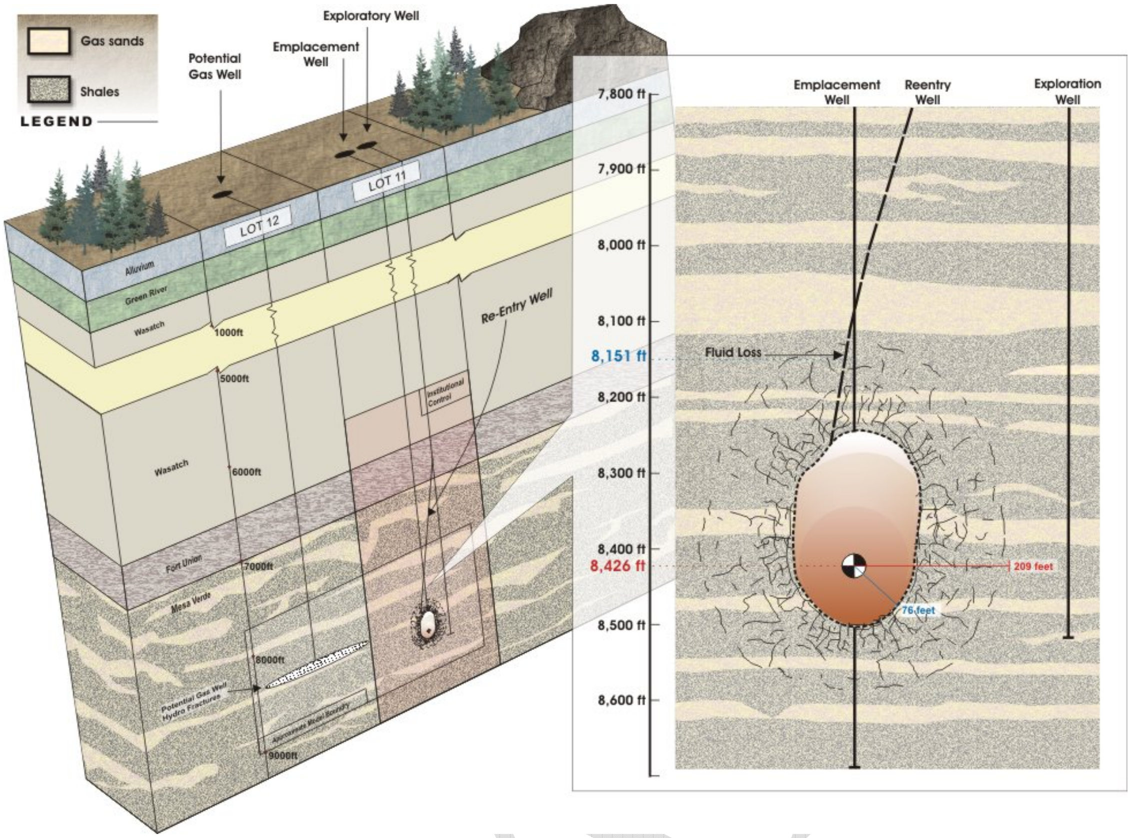


Figure 3. Schematic Cross-section of the Rulison Detonation Zone

Rulison site has increased dramatically. The increase in gas development near the Rulison site has raised concerns about the possibility of encountering residual radioactivity from the area of the detonation.

The COGCC has decision authority over applications for permits to drill oil and gas wells in Colorado and has imposed administrative controls on drillers in the vicinity of the Rulison site. The COGCC notifies DOE of any drilling permit activity within 3 miles of the site and requires adherence to a prescribed sampling and analysis plan that varies depending on distance from the site for approval of permits in this area (URS 2008). Drilling permit applications within a half-mile of the site require a hearing before the commission prior to approval.

1.2 Potential Source of Contamination

The detonation zone at the Rulison site is a potential source of radionuclide contamination that is currently contained in the subsurface. The detonation zone consists of a cavity with a 76-ft radius and an overlying collapse chimney that extends about 275 ft above the detonation level. A high-permeability fractured region surrounds the cavity and chimney and extends an estimated 209 ft radially from the detonation. The top of the chimney was determined during the drilling of the reentry well when the first major fractures were identified at a depth 8,151 ft below ground surface (AEC 1973). The extent of the surrounding fractured zone is based on analysis of data from the reentry well production testing that indicated a 33-fold increase in permeability to a distance of 2.75 cavity radii (Montan 1971; Rubin, Schwartz, and Montan 1972).

Most of the longer-lived radionuclides produced by the detonation are solid at relatively high temperatures and were incorporated within the molten rock as it cooled to form a melt glass at the base of the cavity. Solidified radionuclides can be subject to dissolution by and transport with passing liquids in some environments. However, in the gas-bearing formations at the Rulison site, liquid movement is limited, making any solidified radionuclides that may have dissolved in the cavity essentially immobile. The relative permeability of the formation to liquid is 3 to 4 orders of magnitude lower than the relative permeability to gas, and gas has remained in the formation until it can be extracted from zones near wells using hydrofracturing techniques. Additionally, the tendency of most dissolved radionuclides to sorb to mineral grains would further slow their movement with respect to a potential carrying liquid. Several of the longer-lived radionuclides produced by the detonation in quantities large enough to potentially affect public health or the environment (tritium, krypton-85, and carbon-14) do not solidify at lower temperatures and can exist in either liquid or gas phases. When present in the gas phase, these radionuclides are far more mobile than those bound in the solid phase or those dissolved in the liquid phase. Tritium (an isotope of hydrogen) is primarily present as tritiated hydrogen gas (HT in place of H_2), tritiated methane (CH_3T in place of CH_4), or tritiated water (THO in place of H_2O). Carbon-14 is primarily present as part of the methane molecule ($^{14}CH_4$ in place of $^{12}CH_4$), and krypton-85 is an inert gas. The gas production testing on the reentry well removed almost all the carbon-14 and krypton-85 created by the detonation (AEC 1973), leaving tritium as the most mobile radionuclide that remains in quantities sufficient to pose a potential health concern (10,000 curies produced by the detonation reduced to 7,000 curies after production testing that will have since decayed to 700 curies by late 2009). Tritiated water occurs both as liquid water and as water vapor, allowing it to readily migrate with either the liquid (mobile formation water, limited at the Rulison site) or gas phases (plentiful at the Rulison site). Tritium can also be incorporated in the solidified melt glass, though to be conservative in considering potential migration scenarios, tritium is treated as if all of its mass remains in the liquid or gas phases.

Upward migration of radionuclides to a depth at which they might affect public health or the environment solely by way of natural pathways (with fluids moving through pores and fractures) is extremely unlikely due to the depth of burial (more than 8,000 ft) and the low permeability of the surrounding formations, which limit fluid movement. The detonation zone is in the lower part of the approximately 2,500-ft-thick Williams Fork Formation, more than 1,000 ft below the overlying Ohio Creek Formation, an unnamed formation, and the Wasatch Formation, which have a combined thickness of about 4,400 ft at the Rulison site (Voegeli 1969). The pores of the tight, poorly connected sandstone reservoirs of the Williams Fork contain approximately 50 percent gas and 50 percent formation water (brine) and are isolated within lower-permeability shale. The presence of commercial amounts of gas and the need to use hydraulic fracturing methods to affect even small areas (each well drains roughly a 10-acre area) support the concept of essentially no movement of fluids within a time frame of significance for tritium migration to be of concern. In the absence of wells that penetrate near the detonation zone, there is no realistic pathway for contamination to reach the surface or near-surface. Thus, the most likely tritium transport mechanism at the Rulison site is tritiated water vapor migrating with natural gas to a nearby producing well.

1.3 How Close to the Detonation Zone Can Natural Gas Be Safely Produced?

Institutional controls are legally enforceable spatial boundaries that limit intrusion at a site to a safe distance in order to protect human health and the environment. The institutional controls at Rulison prohibit drilling below the 6,000-ft depth in Lot 11 (NE quarter of SW quarter) of

Section 25, T7S, R95W (Figure 1). Tritium is likely restricted to the vicinity of the detonation zone within the 40-acre Lot 11 boundary. This finding is based on the results of the modeling study conducted by Desert Research Institute (DOE 2007) that calculates potential transport distances using many combinations of sandstone distribution possibilities and hydraulic parameter ranges typical of Williams Fork sandstones. However, just as the blast fractured the formation, increasing the permeability and releasing much of the gas within the detonation zone, each modern gas well is completed using hydrofracturing technology that increases the permeability of local sandstone reservoirs and releases the gas in the vicinity of the well. In all cases, the proximity of gas wells to the Rulison site should be limited to a distance beyond which no interaction between the detonation zone and hydrofracturing zone can occur.

The primary factors that determine a safe distance for a gas well from the detonation are the extent of the nuclear-fractured zone and the maximum distance from a well that hydrofracturing increases permeability. These factors plus others were included in the modeling study, which predicts that, in over 95 percent of the simulations, no tritium above background levels will reach a gas well in Lot 12, 200 ft from the west border of Lot 11 (850 ft from the detonation). Additional recent modeling (Cooper et al. 2009) indicates that by moving the gas-producing well to the center (relative to east-west) of Lot 12 (660 ft from the boundary and 1,310 ft from the detonation), no significant amount of tritium reaches the well in any of the simulations. This location for the simulated gas well is more consistent with the location of actual wells that will be drilled to develop gas reserves to the west of Lot 11. This location also currently limits the possibility that hydrofractures at the simulated well would penetrate Lot 11, which is prohibited. Each lot is approximately 40 acres, and the typical well drains an east-west elongate area of 10 acres. This results in four wells centered within a lot east-west and equally spaced north-south as the typical developed configuration. Model well locations are shown on Figure 1.

The extent of the nuclear detonation zone is known from analysis of reentry-well production test data that indicate nuclear fracturing increased formation permeability out to a distance of 209 ft from the detonation point. Nuclear fracturing distance was treated as a deterministic (fixed) parameter in the model (the same distance was used for all simulations). The average and maximum extents of typical hydrofractures are known based on data from the many gas wells in the Piceance Basin. Hydrofractured zones, which elongate in the direction of the natural fracture trend of the Williams Fork Formation, have an average propped length (kept open by sand injected with the hydrofracturing fluid) of 200–300 ft and can reach lengths up to 600 ft from the well in the direction of the natural fracture trend. Because of the range in possible propped hydrofracture length, it was treated as a random parameter in the model (the length for each simulation was selected from a probability distribution based on industry data).

The results of the most recent conservative modeling provide confidence that wells at the half-mile radius, even in the direction of the natural fracture trend, are safe for gas production. The half-mile radius is 2,640 ft from the detonation, yet no significant amount of tritium reached the hypothetical gas well for any simulation with a well 1,310 ft from the detonation (center of Lot 12 to the west). Even if tritium were to reach a gas well, the risk is low in that there is no reasonable exposure scenario that would endanger public health. Almost all of the tritium (migrating as tritiated water vapor along with the methane gas) would be captured at the wellhead where the water vapor condenses and is removed from the gas prior to entering the gas distribution system. Despite the low risk, a cautious approach to gas development near the Rulison site is recommended and is described in the following sections.

1.4 Path Forward Objective

The objective of this document is to encourage gas developers to adopt a conservative, staged-drilling approach that allows gas reserves near the Rulison site to be recovered in a manner that minimizes the likelihood of encountering contamination. There is no evidence that leads DOE to suspect that contamination from the Rulison site detonation has or will ever migrate beyond the current institutional control of Lot 11. The approach presented below is suggested as a way to further enhance public safety while allowing additional data to be collected to confirm the conclusion of limited contaminant migration. Success of the approach will depend on the joint cooperation of companies with lease interests near the Rulison test site, the COGCC, and DOE. The public should be informed once a comprehensive approach has been adopted, and subsequently kept informed on drilling progress and monitoring results.

2.0 Guidelines for Gas Development near Rulison

A staged approach that initially uses conservative modeling but primarily relies on the collection of data to determine a safe drilling distance from the Rulison site is recommended. The results of the original model and the results of an additional set of model simulations that apply more conservative transport parameters indicate that gas-production wells can safely be located in the lots west and east of the Rulison site so long as the hydrofractures emplaced during well completion remain outside of the institutional control of Lot 11. The simulated tritium concentration at a hypothetical well located west of the site, in the center of Lot 12, is below background for all simulations during the life of the well.

The first stage of the proposed approach calls for identifying the orientation and potential variability of the natural fracture trend in the area by collecting data at wells drilled and completed approximately 1 mile from the Rulison site (1.25, 1.0, and 0.75 miles). If sampling and analysis results from the 1-mile wells confirm the lack of contamination at this distance, wells just outside the one-half-mile hearing radius can then be drilled. If possible, it is recommended that the initial half-mile wells be located north and south of the site, normal to the natural fracture trend and detonation zone. This places the initial half-mile wells in a location where the low-permeability direction of the formation and least likely growth direction of the hydrofractures will be toward the detonation zone, minimizing the likelihood of transport. Once installed and completed, the wells surrounding the half-mile radius will act as a focused monitoring network, with sampling and analysis of fluids from the wells confirming that no contaminant transport occurs beyond the half-mile radius. One well, Battlement Mesa 36-13, has already been drilled near the half-mile radius south-southeast of the site, and no contamination has been detected in this well. The orientation of the natural fracture trend should be confirmed by the best available technology at several of the half-mile wells prior to considering wells nearer the detonation.

DOE recommends that wells within the half-mile radius are staged based on sampling results from wells just outside the half-mile radius and on the orientation of the natural fracture trend. The initial wells inside the half-mile radius should be located north and south of the detonation to minimize the possibility of encountering contamination. Drilling wells in line with the predominant fracture trend and the detonation within the half-mile radius (Lot 12 to the west and Lot 10 to the east) is recommended after locations to the north and south are drilled and monitored. An additional conservative approach recommends that when wells are drilled in Lot 12 and Lot 10, completing and producing from sandstone reservoirs at the interval affected by the detonation should be delayed. This suggested approach will require the cooperation of gas operators in the area, the COGCC, and DOE.

DOE does not believe the presented approach is a burden on gas operators, but rather an approach that a reasonably cautious operator would have likely developed independently. DOE believes that it would be helpful if gas operators with lease holdings in the vicinity of the site coordinated their planning for gas development in the area with COGCC and DOE to reduce the possibility of any misunderstanding. For example, given DOE's stated interpretation that no contamination is expected to ever migrate beyond Lot 11, an operator might apply for a permit to drill within the half-mile radius in the most likely direction of potential transport before other wells in safer directions have been installed. Though DOE believes it is unlikely the operator would encounter contamination, the suggested staged approach is preferred because it adds another layer of safety that only requires a better planning sequence for well installation. This path forward assumes that the current industry Sampling and Analysis Plan (URS 2008) for wells inside the 3-mile notification area will be in effect until a focused network around the site is sufficiently developed. DOE is currently developing it own sampling and analysis plan to supplement the industry plan.

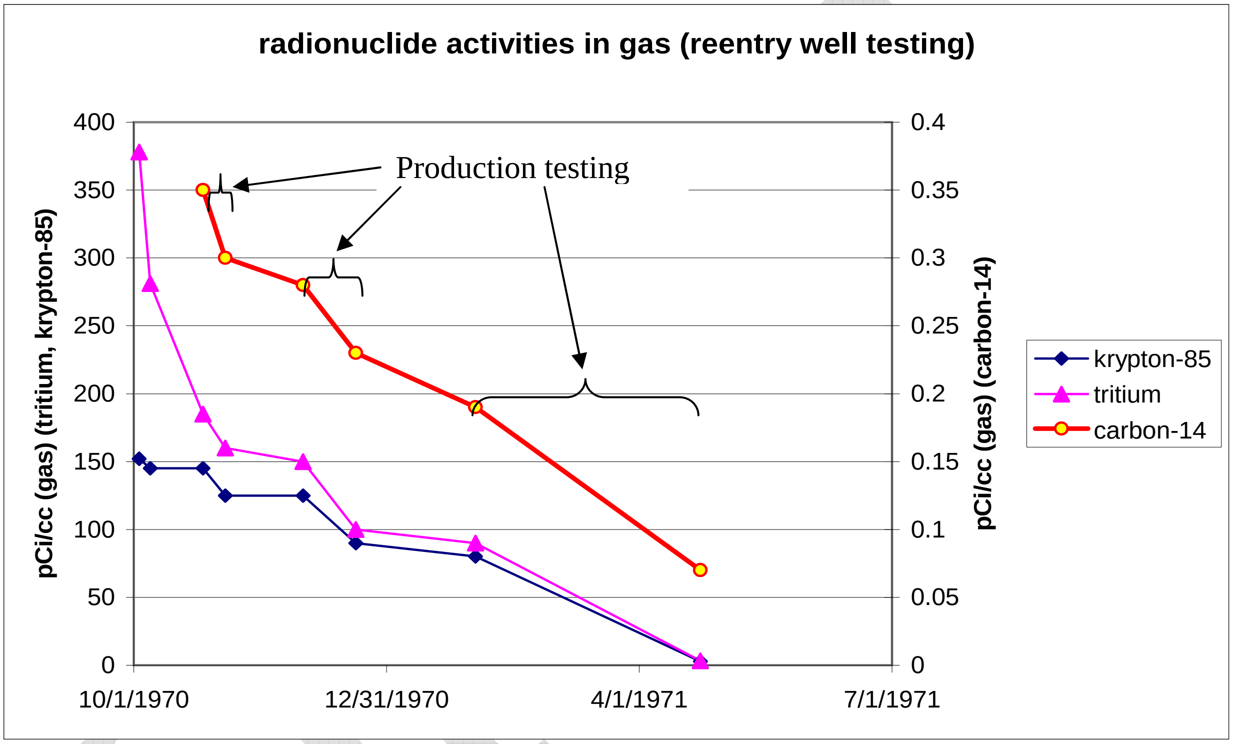
2.1 Selection of Tritium as the Contaminant of Concern

The selection of tritium as the only contaminant of concern for gas production is consistent with the gas testing results from the reentry well given in the Project Rulison Manager's Report (AEC 1973). The reentry well produced 455 million cubic feet of gas, and the only radionuclides detected were tritium, krypton-85, carbon-14, argon-37, argon-39, and mercury-203. On the basis of estimated inventories of radionuclides produced by the detonation and the amounts removed by production testing, tritium is the only mobile radionuclide that remains in any significant quantity in the detonation zone. This finding is shown in Table 1 and is derived from the Project Manager's Report (AEC 1973), Nork and Fenske (1970), Reynolds (1971), and separate calculations. Nonvolatile isotopes such as those of uranium and plutonium are not present in the gas phase and were not detected in samples produced from the reentry well.

Table 1. Radionuclides in Reentry Well Gas

Radionuclide	Estimated from Detonation (curies)	Estimated Removed by Production Testing (curies)	Half-life	Estimated Remaining 2009 (curies)
Tritium	10,000	2,824	12.32 years	700
Krypton-85	1,100	1,064	10.8 years	< 10
Carbon-14	<1	2.4	5,730 years	< 1
Argon-37	10–100	Not available	34 days	< 1
Argon-39	2–20	Not available	260 years	N/A
Mercury-203	N/A	0.0001	47 days	< 1

The minute amounts of mercury-203 (0.00004, 0.00003, and 0.00003 curies) removed in the first, second, and third production tests are consistent with the amount found naturally in the formation (Reynolds 1971). The original estimate of less than a curie of carbon-14 (Nork and Fenske 1970) was low, because more was removed than was thought to have been produced. The declining activities of the radionuclides produced in the gas are shown on Figure 4. The tritium concentrations in the extracted gas declined similarly to those of the other volatile radionuclides, even though approximately 7,000 curies of tritium remained. This is primarily attributed to the likelihood that after the tritiated hydrogen gas and tritiated water vapor were removed during the gas-flow testing, the remaining tritium was present as tritiated liquid water with some possibly incorporated in the melt rock. Over time, a portion of the tritiated liquid water will move into the gas phase as water vapor.



pCi/cc = picocuries per cubic centimeter

Figure 4. Activity of Radionuclides in Gas from the Production Tests on the Reentry Well

2.2 Modeling

The contaminant transport model for the site was revisited with the intent of determining the nearest distance, in the direction of greatest permeability from the detonation, at which a hypothetical gas-producing well could be located with no reasonable expected risk of encountering contamination. The initial modeling suggested that it would likely be safe to place a production well near the minimum legal distance (200 ft prior to 2005) from the Lot 11 boundary (within Lot 12) along the trend of natural fracturing. However, the restrictions that prevent removal of material from Lot 11 make it unlikely that a well would be drilled this close to the lot boundary. Over 95 percent of the simulations with the producing well 200 ft from the lot boundary showed no breakthrough above background levels, even though some simulations had hydrofractures that intruded into Lot 11. The additional simulations undertaken in the modeling addendum focused on more conservative, yet still reasonable, transport parameters than those used in the initial modeling (DOE 2007) in an effort to add an extra margin of safety to the interpreted modeling results.

The results of the additional modeling indicated that tritium levels for a well located in the center of Lot 12 (660 ft from the Lot 11 boundary) only slightly exceeded background levels for the most conservative simulations and were well below background levels for all simulations that use a partitioning coefficient consistent with formation temperatures. The partitioning coefficient specifies how much water is in the form of liquid water (immobile) or water vapor (mobile). The model results provided confidence that the half-mile radius is safe and indicated that even the most vulnerable well location in a lot adjacent to the site was unlikely to be affected. However, on the basis of possible unrecognized variations from model assumptions, a cautious approach is warranted. The nuclear fracture radius used in the model was 263 ft (80 meters) instead of the 209 ft (63.7 meters) reported from the reentry well pressure analysis. Due to the model being discretized into 20-meter grid blocks, the extent of the nuclear fractures in the model was set at 80 meters instead of 60 meters to be conservative.

2.3 Determination of Natural Fracture Trends Near the Site

The Williams Fork Formation of the Piceance Basin has a natural fracture field that generally trends east to west, though the orientation can vary somewhat depending on location within the basin. The permeability of the formation is greater in the direction of the natural fracture trend, and hydrofractures used to further increase permeability during well development tend to elongate in this direction. The orientation of the fracture trend in a given area can be measured using several methods. The dipole sonic log can be used to determine the minimum and maximum principal stress directions within the formation, which can then be used to infer the stress field orientation. Microseismic mapping uses geophones placed in one or more wells near a well being completed to record hydrofracture propagation, which tends to follow the higher-permeability direction of the natural fracture field.

Microseismic mapping was used to detect average fracture orientation in a portion of the Rulison Field, a gas-producing area located approximately 6 to 8 miles northeast of the Rulison site. Results from the microseismic testing, illustrated in Figure 5, identified a fracture orientation of N75°W, with a local range of plus or minus 10 degrees (Wohlart et al. 2005). In the Grand Valley Field (approximately 8 miles northwest of the test site), the average fracture orientation was determined to be N84°W, with a local range of plus or minus 5 degrees (Wohlart et al. 2005). Until data are collected near the Rulison site, it will be assumed that a fracture orientation of N75°W also applies to the area surrounding the Rulison site.

As part of the path forward, it is recommended that the natural fracture orientation near the Rulison site be confirmed prior to drilling near the half-mile radius. Noble Energy has applied for 25 permits to drill west of the site, with bottom-hole locations that range from 0.75 to 1.25 miles from the test point (Figure 5). These locations are good candidates for dipole sonic logs and possibly a microseismic survey. A dipole sonic log was run in Noble Energy well BM 26-34A, 3/4 of a mile west of the site, and the results confirm the east – west orientation of the natural fracture trend. The results of the dipole sonic logs and the microseismic mapping, if performed, will be used to guide the drilling sequence of future wells located just outside the half-mile hearing radius.

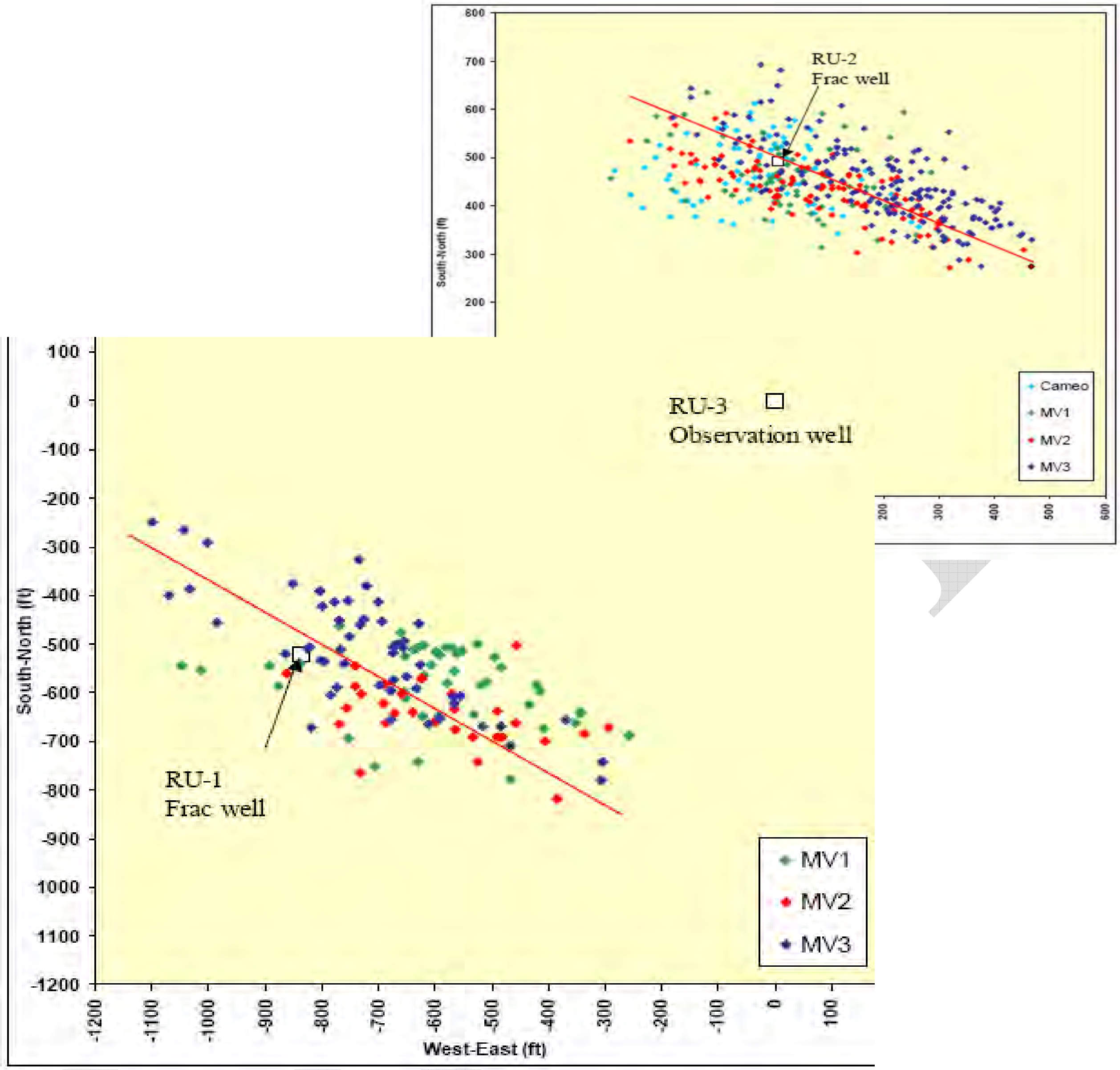


Figure 5. Microseismic Mapping of the Hydrofracturing of Two Wells

Mapping was conducted at different times during the winter of 2001–2002 using the same observation well (RU-3) in the Rulison Field (modified from Wohlart et al. 2005). The points are microseisms, small seismic events associated with hydrofracture propagation. The point colors represent different hydrofracture stages (sandstone reservoirs fractured as a group within a given depth range; Cameo is the deepest and Mesaverde-3 is the shallowest). Note that the hydrofracture wing nearest the observation well has an apparent length greater than the opposite wing. This is interpreted as an artifact of detection distance from the observation well, not actual asymmetry of hydrofracturing extent.

2.4 Confirmation That the Half-Mile Radius Is Safe

It can be confirmed that locations beyond and approaching the half-mile hearing radius are safe for natural gas development by drilling a series of gas wells just outside this radius, producing the wells, and monitoring them for radionuclides potentially associated with the nuclear test. The wells will be drilled by gas operators with lease interests near the site as part of their ongoing development of gas reserves in the area. These wells, depicted as ovals in Figure 6 to indicate an approximate hydrofracture extent, should confirm that contamination has not migrated appreciably from the site and will also act as a focused network that monitors for any contaminant migration that might occur in the future. One well, Battlement Mesa 36-13, has already been drilled near the half-mile radius south-southeast of the site, and no contamination has been detected in this well.

As previously discussed, a conservative approach to this confirmation process would be to place the first of the half-mile wells almost directly north and south of the test site (assuming a general east-west natural fracture trend). Subsequent wells would be drilled progressively closer to the linear band aligned with the predominant natural fracture trend and the test site, and wells located within that band would be installed last. All well locations at the half-mile distance are considered safe, though following the staged approach, even at this distance, would be preferred if possible. At this distance, the timing of installing and producing the north-south wells first and then the east-west wells is a suggestion and need not be rigidly adhered to or required by the COGCC if there are other overriding concerns, such as the logistics of locating new drill pads. Test findings from the wells installed at the half-mile radius will be used to make decisions regarding the locations and construction of subsequent wells.

The tests that can be conducted at the wells as they are installed include dipole sonic logs (information about the orientation of the natural fracture trend), formation micro-imaging logs (which provide images of fractures in wellbore walls), and geophysical logs (gamma ray, resistivity, density, neutron, and sonic), most of which are run on all new wells to gain information on the lithology, permeability, porosity, and gas content of the formation intercepted by the well. Conducting a microseismic survey during the hydrofracturing of one of the half-mile wells could be considered to confirm fracture orientation from the dipole sonic logs and to estimate hydrofracture distance. Collecting rock core from above, within, and below the detonation horizon, at one of the half-mile wells could also be considered to show that the formations opposite the detonation depth were not materially affected by the blast.

The application for a permit to drill wells just outside the half-mile radius does not require a COGCC hearing. If a permit request is submitted for a well location within the half-mile hearing radius before a number of wells are installed just outside this distance, COGCC would have to make any decision without the benefit of additional data from the half-mile wells. The suggested approach allows all parties involved to make more-informed decisions regarding potential well installations within the half-mile hearing radius.

2.5 Wells Within the Half-Mile Radius

The COGCC notifies DOE when they receive applications for drill permits within 3 miles of the Rulison site and considers comments from DOE in the approval process. For well permit applications inside a half-mile of the site, a hearing before the commission is required. DOE does not encourage wells within the half-mile radius until data have been collected from wells just outside the half-mile radius. The data to be collected include not only information about the orientation of the natural fracture trend near the test site, but more importantly, concentration data from fluid samples at these wells. DOE does not believe that contamination has migrated or will migrate beyond Lot 11. The support of wells inside the half-mile radius would be more convincing to both the public and regulators if a data set confirmed the lack of radionuclides at

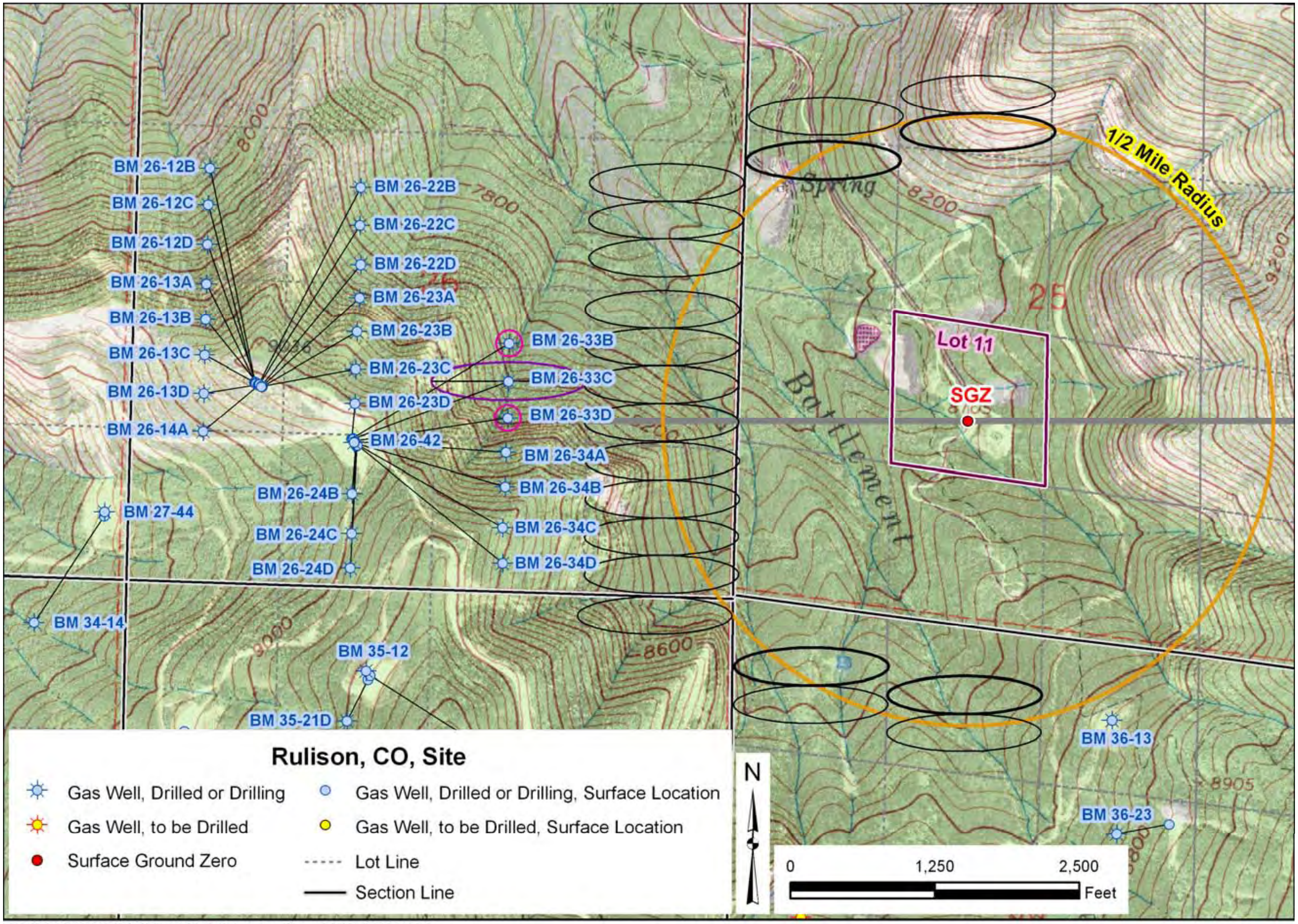


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Figure 6. Map of the Rulison Area Showing Potential Well Locations for Production and Monitoring Outside the Half-Mile Hearing Radius (ovals indicate the extent of influence of potential half-mile well locations). Planned well locations shown above were in the process of being drilled at the time of this report.

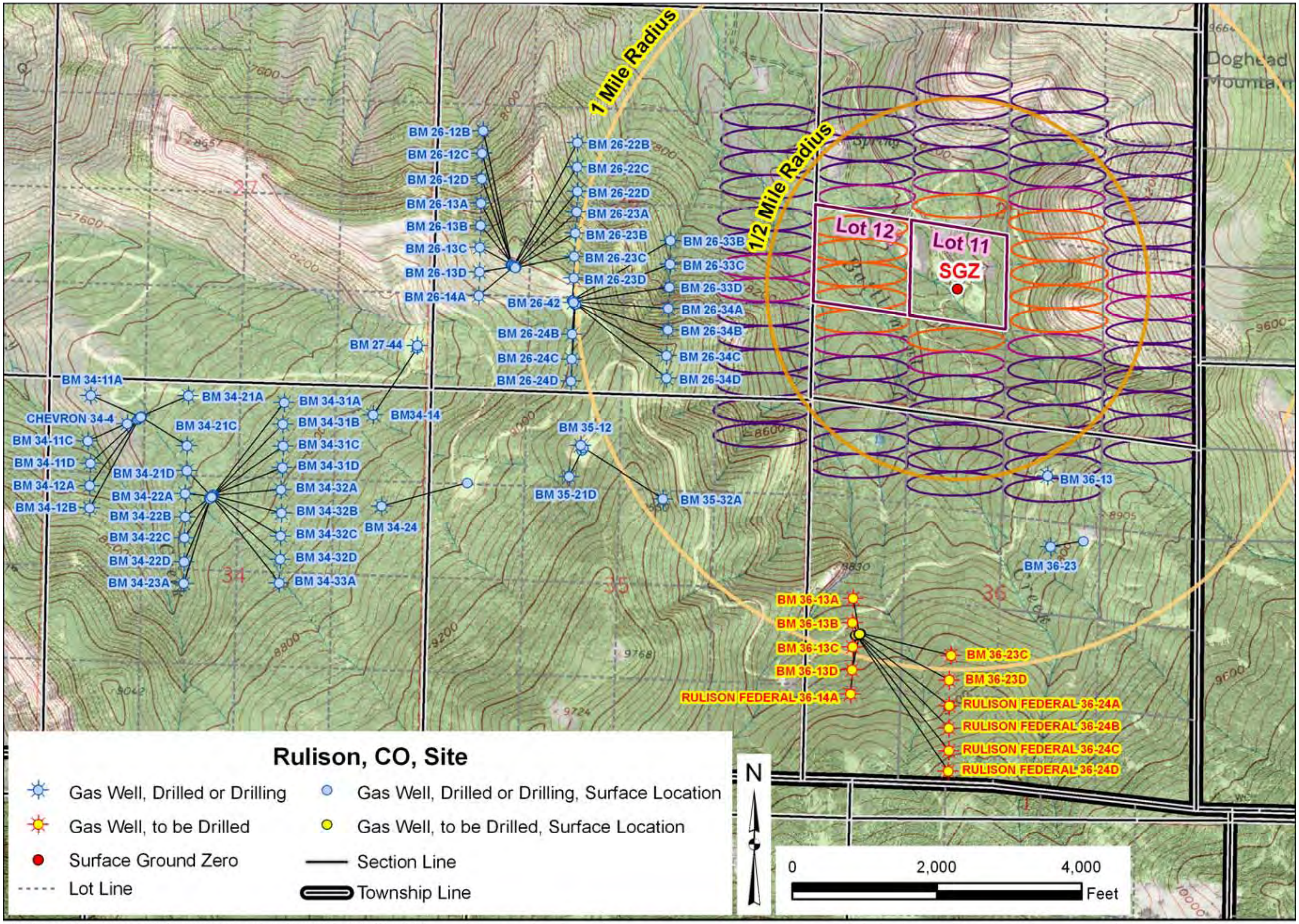

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Figure 7. Rulison Area Map Showing Potential Well Locations for Production and Monitoring Outside and Inside the Half-Mile Hearing Radius. Possible well locations (ovals) in the vicinity of the Rulison site, color coded by relative risk of encountering any contamination (based on distance and orientation from the site).

wells just outside the half-mile radius. As in the case of the half-mile wells, it is recommended that the first wells installed within the half-mile radius be located almost directly north and south of the detonation zone (see bolded ovals in Figure 6), in the least likely transport direction. To ensure that the initial wells are drilled in the least likely transport direction, it is also recommended that the natural fracture orientation in the vicinity of the Rulison site be confirmed by the best available technology on at least one of the half-mile wells before drilling within the half-mile radius is allowed. Subsequent wells could then be installed in a sequence that gradually approaches the higher-risk transport direction, currently believed to be roughly east-west of the site. Color-coded hydrofracture ovals in Figure 7 show how this gradual approach to developing the area within the half-mile radius could be carried out.

It is recommended that the gradual approach suggested for developing gas reserves just beyond the half-mile radius be more closely adhered to for drilling within the half-mile radius. Testing and monitoring results from each newly installed well should be used to evaluate successive well locations as to their potential risk. If testing confirms that the natural fracture trend is oriented east-west at the site, the areas of greatest risk will be Lot 12, west of the site and Lot 10, east of the site. Drilling and producing from these two lots is not recommended until the lack of radionuclide contamination is confirmed by data from producing wells located in safer directions within the half-mile radius.

When wells are eventually drilled in the lots immediately west and east of the test location, completing and producing from sandstone reservoirs at the interval affected by the detonation should be avoided until data indicate that it is unlikely that test-related radionuclides are present at this location. The interval affected by the detonation is considered to be the zone from just above the top of the chimney to the bottom of the cavity, approximately from an elevation of 50 ft above to 400 ft below mean sea level. For example, micro-imaging logs would indicate whether this level has increased fracturing relative to the rest of the gas-bearing formation. Under no circumstances shall a well be located such that encroachment into or removal of materials from Lot 11 might occur. This includes all hydrofractures, propped or not, and flow-inducing gradients by way of production near Lot 11 that could cause contaminant migration from Lot 11.

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